Their sizes, locations, and directions are of importance. They should be entered upon the plan.

4. If the tree is splintered, notes should be made of the positions of the most distant splinters, as well as of all the large ones. The positions of the latter should be carefully determined; the distance, position with reference to the tree, and the position of the bark are of importance. Do they appear to have hit violently upon an end; if so, upon which; if not, is there any evidence of which part bore the brunt of the blow? (The main evidence is to be sought in the ground and in the soiling of the splinter.) All significant features, such as those which relate to the nature of the breaks, should be noted and photographed.

5. The nature of the splintering should be noted. Are all portions of the splintered material damaged in the same way, or is there indication of a path, or of paths, of peculiar damage? In the latter case, how do these paths differ from the rest, how are they situated, do they reach the surface at any point; if so, where, and how is the bark affected at that point? What are the sectional dimensions of the paths, and how do they vary from point to point? Trace the paths as far as possible; do they encounter any knots and; if so, how do they pass around them?

6. Search for punctures of the bark; remember that they may be very small. Are their borders scorched? Do they appear to have been made by a mechanical force acting from within outward, or the reverse, or is there no evidence bearing upon this point? The position of each puncture should be carefully noted, so that it can be correlated with the other observations. If only a segment of the tree is splintered, an especially careful search for small punctures should be made in the neighborhood of each boundary of the splintered segment. In so far as possible, reconstruct the tree in the region of each puncture so as to determine the size of the hole, depth of penetration, the angle it makes with the vertical, and the plane in which it lies; the latter should be entered on the plan.

7. Note carefully the nature and the location of the damage to the bark and to the sapwood. Distinguish between a mere mechanical tearing of the bark as a result of the splintering of the tree and damages of other kinds.

8. If practical, throw the tree and note the location, extent, and nature of the damage to the roots, photographing everything of interest. Note carefully how the roots lie with reference to the ground plan. Section the tree at such points as seem desirable.

9. Nothing should be moved until everything of interest regarding its original position has been recorded. But after such records have been made, exhibits should be collected, carefully labeled, and preserved, at least until after a detailed report has been written.

10. Above all things, trust nothing to your memory; upon the spot, make written notes of all observations and of the impressions which they produce upon you. If practical to do so, move nothing until after you have written up and studied all the notes which you can otherwise obtain; you will frequently find that additional observations are desirable.

OCEAN TEMPERATURES AND SEASONAL RAINFALL IN SOUTHERN CALIFORNIA

A REVIEW OF THEIR RELATION BASED UPON RECORDS OF THE PAST NINE YEARS

By GEORGE F. MCEWEN, Physical Oceanographer

[The Scripps Institution of Oceanography, La Jolla, Calif., December 28, 1925]

The continuous record of seasonal rainfall at San Diego began in 1850, and may be regarded as typical of southern California in the variation from year to year. What is the likelihood of being able to predict the rainfall for a given year solely from a rainfall record? On examining the record for San Diego, which is the longest available in this region, there appears to be no definite relation of the rainfall during any season either to the rainfall of one year[1] or to that of any sequence of years preceeding it. For example, a rainfall above the average is just as likely to follow a dry year as a wet year. The distribution in time, of seasonal rainfall, appears to be as fortuitous as the result of coin tossing or drawing odd and even numbers from a pack of numbered cards.

Although it is impossible to predict what the next season's rainfall will be solely from the record of rainfall, it is possible to state the probability that it will be between any assigned limits. A suitable frequency curve, fitted to the 75 values of the seasonal rainfall at San Diego, yielded the results entered in Table 1.

TABLE 1.—*Frequency, in number of times per hundred that the rainfall at San Diego may be expected to have a value between the given limits*

Frequency	0.8	9.2	20.7	21.8	16.7	12.3	7.6
Limits	0-3.3	3.3-5.3	5.3-7.3	7.3-9.3	9.3-11.3	11.3-13.3	13.3-15.3
Frequency	4.1	3.0	1.5	1.0	0.5	0.3	0.2
Limits	15.3-17.3	17.3-19.3	19.3-21.3	23.3-25.3	25.3-27.3	27.3-29.3	29.3

[1] In the paper by L. E. Blochman, following, the reader will find a discussion, based on the San Diego rainfall record, which indicates a relation between San Diego summer rains and the rainfall of the ensuing season in southern California.—Ed.

From the frequency distribution of the rainfall, estimates can be made of the chances of having a drouth of given intensity (number of successive years when the rainfall is below a given amount) within any period, 50 or 100 years. For example, in an 11-year interval we may expect 8 or more years to have a rainfall less than 9.2 inches about once in a century.

About once in 50 years an 11-year period will contain 5 or more years during which the seasonal rainfall is less than 7.3 inches. The 11-year period from 1893 to 1904 corresponds to both of these cases. It contained 8 years during which the rainfall was less than 9.2 inches, and 5 years during which it was less than 7.3 inches. Computing the chances of a flood or drouth of given intensity is one kind of prediction, although no information regarding any particular year is thus obtained. Such predictions are of value to engineers in the economic design of storage systems for conserving the maximum amount of water.

Considerable work has been done in attempting to discover cycles or periodicities in various natural phenomena. The possibility of cycles in sun spots, temperature extremes, drouths, etc., and attempts to find correlations based upon such phenomena has aroused the interest of able investigators, as well as those less qualified to deal with such problems. In many cases the advocates of certain cycles have not been able to establish their claims. The problem of determining cycles empirically from observational data is in general elusive and difficult. Many people believe that the seasonal rainfall at San Diego is cyclical, and that the period is about 20 years. While periods of light and heavy rainfall do alternate in general, the length of the corresponding time interval appears to vary too much from its average to justify applying the term cycle.

A simple rainfall sequence at San Diego, involving alternate intervals of 10 and 20 years was discovered by Mr. H. F. Alciatore, a fomer meteorologist of the San Diego Weather Bureau. The rainfall expressed in percentages of the average for the whole record is entered in Table 2 under the interval.

TABLE 2.—*Rainfall at San Diego, in per cent of the normal, during a sequence of intervals of 10 years, 20 years, 10 years, etc.*

1846–1856	1856–1876	1876–1886	1886–1906	1906–1916	1916–1936
108	90	122	96	109	93

The four middle intervals are complete, but the available record did not begin until the middle of the first interval, and has extended only to the middle of the last one. Beginning with 1846, the table indicates, consistently, that during alternate intervals of 10 and 20 years the average rainfall is alternately above and below the normal. This is the only rainfall sequence for San Diego that the writer has seen which holds consistently throughout the whole length of the record. It suggests the presence of a 30-year cycle. But values of the seasonal rainfall, above and below the normal, are irregularly distributed through both the intervals of high average and of low average rainfall.

Forecasts based entirely upon investigations of the rainfall record do not provide an estimate, in advance, of what the rainfall for the coming season will be. The conclusion is that specific forecasts of seasonal rainfall must involve the relation of rainfall to causes that can be observed and measured. Only as we approach to an understanding of the processes at work to produce rain, and as adequate observations are made and become available, can we expect to succeed in the difficult problem of forecasting. At present we are only near the beginning of such a huge undertaking that promises to involve not only investigations of the atmosphere and the sea, but the sun as well. The results of extensive investigation demonstrate the controlling influence of the oceans on the climate and weather of continental areas. An unusual amount of heat reaching any part of the ocean results in changes in atmospheric pressure and temperature gradients in the ocean. Thus changes in winds, ocean currents, evaporation, and precipitation arise. There is accordingly a continual interaction between the ocean and the atmosphere, as equilibrium is approached, but never reached. Moreover, it is now generally admitted that changes in the surface layer of the ocean can be observed months before the occurrence of their effect on the weather of a neighboring continent.

Since 1915 daily surface temperatures of the ocean have been observed at the end of the Scripps Institution Pier. An examination of the records indicated that the low rainfall during 1917–18 was preceded by summer ocean temperatures several degrees higher than the temperatures during the summer of 1916. In 1918 the summer temperatures did not return to normal. This suggested that a low seasonal rainfall for 1918–19 might be expected. (McEwen, 1918, p. 18; see bibliography.) The 1918–19 season proved to be even drier than the previous one. The inverse relation between summer ocean temperatures and the following seasonal rainfall indicated by these three years lead to the consideration of a possible temperature-rainfall relation as one of the institution's problems. It was also decided to publish experimental forecasts from the beginning, rather than to withhold the information until a long enough period of observations had been made to test adequately the validity of the relation.

The average seasonal rainfall at six representative stations has been used as an index of the rainfall over the coastal region of southern California. The following stations were selected on account of the length and continuity of their records, and their geographical distribution: Bonita, San Diego, Escondido, Tustin, Corona, and Los Angeles. The temperatures averaged for the interval from August 1 to October 15 were found, by trial, to give the most consistent results. The usual interval from July 1 to July 1 of the following year is used for the seasonal rainfall. These results to date are presented in Table 3.

TABLE 3.—*Summer ocean temperatures at La Jolla, and seasonal rainfall during the following year in southern California*

Year	Temperature	Departure from 9-year mean	Average of the seasonal rainfall at 6 stations	Departure of rainfall from 9-year mean
1916–17	66.4	−1.1	12.9	1.5
1917–18	68.8	1.3	10.9	−.5
1918–19	69.3	1.8	8.9	−2.5
1919–20	66.7	−.8	12.2	.8
1920–21	67.8	.3	10.8	−.6
1921–22	66.4	−1.1	21.7	10.3
1922–23	67.8	.3	9.0	−2.4
1923–24	69.5	2.0	8.7	−2.7
1924–25	65.5	−2.0	7.8	−3.6
1925–26	66.9	−.6		
9-year mean	67.5		11.4	

In eight out of the nine pairs of temperature and rainfall departures the signs are unlike, thus indicating a negative correlation between temperature and rainfall. From the average relation between temperature and rainfall departures shown by the table, the rainfall for 1925–26 was estimated to be 12.6 inches, or about an inch above the nine-year average.

The La Jolla temperatures have been used because of the length of the record. A program of daily temperature observations at other coast stations has been carried out since the La Jolla record began. These additional observations provide a means of obtaining some idea as to the size of the ocean area that behaves, approximately as a unit. The average ocean surface temperature at each of three southern California stations, La Jolla, Oceanside (30 miles north), and Hueneme (100 miles north) is presented in Table 4.

TABLE 4.—*Average ocean temperature at the surface during the period, August 1 to October 15 at each of three coast stations, La Jolla, Oceanside, and Hueneme, in southern California*

	La Jolla	Oceanside	Hueneme	Average of 3 stations
1916	66.4	[1] (64.8)	[1] (59.7)	63.6
1917	68.8	(67.2)	(62.1)	66.0
1918	69.3	(67.7)	(62.6)	66.5
1919	66.7	(65.1)	60.7	64.1
1920	67.8	(66.2)	61.0	65.0
1921	66.4	64.8	60.1	63.8
1922	67.8	67.0	60.8	65.2
1923	69.5	67.7	61.1	66.1
1924	65.5	63.5	58.1	62.4
1925	66.9	65.2	61.0	64.4
Mean	67.5	65.9	60.7	64.7

[1] Entries in parenthesis, ( ), have been estimated from the temperature at La Jolla from the average difference between the temperature at La Jolla and the other stations based upon the remaining observed values.

The consistent variation of temperature shown by Table 4 indicates that any one of the stations may be be used as an index of conditions over a large area. Since 1921, during a period of several months, from spring till autumn, frequent temperature observations have been made at two stations, one 5 miles west of the Scripps Institution Pier, and one 10 miles west. Weekly averages of these temperatures have varied consistently with those observed at the pier, thus affording additional evidence that pier temperatures are a reliable index of conditions throughout an extensive area. Evidence that temperature variations at inshore stations may be indicative of corresponding changes in a region extending hundreds or even thousands of miles away is afforded by observations from ships plying between San Francisco and Hawaii. Surface water temperatures taken from San Francisco about halfway to Hawaii were averaged by quadrangles 2° on a side or about 120 miles square for the period of 11 weeks from August 1 to October 15 in 1921 and 1922. About 300 temperatures were available for each period. The results are entered in Table 5, which shows that in 1922 the water was 1.5° F. warmer than in 1921. This difference is in agreement with Tables 3 and 4.

TABLE 5.—*Average surface temperature in two-degree quadrangles from San Francisco half way to Hawaii during the period, August 1 to October 15 in 1921 and 1922*

1921	58.5	61.2	64.4	65.1	65.0	68.0	66.7	70.5
1922	60.0	61.2	65.7	66.7	70.0	68.5	69.4	71.2
Diff.	−1.5	0.0	−1.3	−1.6	−5.0	−0.5	−2.7	−0.7

							Mean of all
1921	71.5	69.7	70.5	68.4	69.0	70.7	67.1
1922	72.0	70.3	71.1	71.2	70.0	73.0	68.6
Diff.	−0.5	−0.6	−0.6	−2.8	−1.0	−2.3	−1.5

The average temperature at La Jolla, Oceanside, and Hueneme (last column of Table 4) will now be considered in relation to the seasonal rainfall in each of several selected regions in southern California. Seven groups of rainfall stations having a sufficiently long record have been selected with reference to geographical differences. The stations making up these groups are listed below, each group being designated by a letter for reference.

A—Bonita, San Diego, Escondido, Tustin, Corona, and Los Angeles (low altitude and not far from the coast).

B—Crane Valley Reservoir, Huntington Lake, Kernville, Tule, and Yosemite (high altitude and farthest from the coast).

C—Azusa, Kaweah No. 1, Lytle Creek, Borel, Mill Creek No. 3, Santa Ana River No. 1, and Sierra (intermediate altitude and distance from the coast).

D—Lower Otay, Bonita, Escondido, El Cajon, San Diego, Barrett Dam, Diverting Dam, El Capitan, Morena Reservoir, and Cuyamaca (San Diego County stations ranging from a low altitude near the coast to a level of 5,000 feet).

E—Morena Reservoir and Cuyamaca (high altitude stations in San Diego County, about 75 miles from the coast).

F—Lower Otay, Bonita, Escondido, El Cajon, and San Diego (low altitude stations in San Diego County, the group farthest south).

G—Huntington Lake (highest altitude, farthest from the coast, and in the group farthest north).

A general idea of the location and area of the regions corresponding to these groups is presented by the map, Figure 1.

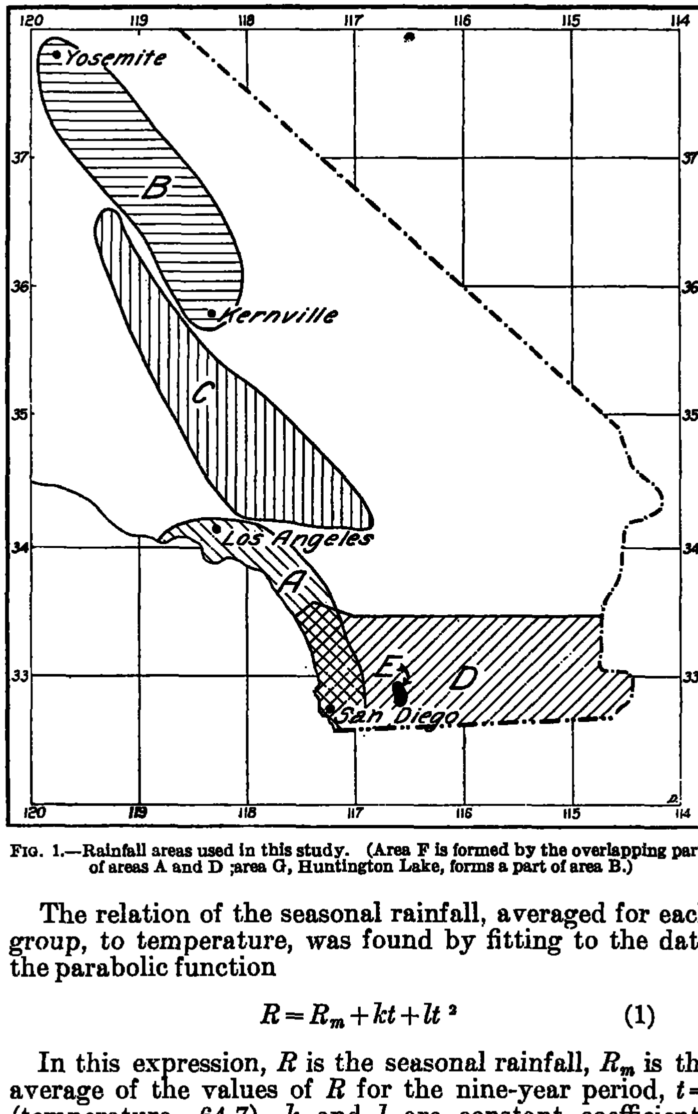

FIG. 1.—Rainfall areas used in this study. (Area F is formed by the overlapping parts of areas A and D ;area G, Huntington Lake, forms a part of area B.)

The relation of the seasonal rainfall, averaged for each group, to temperature, was found by fitting to the data the parabolic function

$$R = R_m + kt + lt^2 \qquad (1)$$

In this expression, R is the seasonal rainfall, R_m is the average of the values of R for the nine-year period, $t=$ (temperature − 64.7), k and l are constant coefficients depending upon the way in which the rainfall varies with respect to temperature. The values of the constants R_m, k, and l are presented in Table 6.

TABLE 6.—*Tabulation of the values of the constants in the temperature-rainfall formula (1) grouped according to the regions* A, B, C, *etc.*

Group	K	L	R_m
A	−2.3	0.22	11.4
B	−2.2	.06	26.5
C	−3.3	.19	23.4
D	−3.2	.28	16.8
E	−4.0	.28	29.8
F	−2.7	.29	11.7
G	−1.4	.10	27.7

All of the data are assembled in Table 7, arranged according to years. The computed values of the rainfall, R result from substituting the temperature in formula (1).

TABLE 7.—*Seasonal rainfall R and departure r from the 9-year average for several groups of stations in southern California, observed and computed from ocean temperatures T.*

(See p. 485 for explanation of groups A, B, C, etc.)

Station group	Ocean temperature		A Observed		A Computed		B Observed		B Computed	
Year	T	t	R	r	R	r	R	r	R	r
1916–17	63.6	−1.1	12.9	1.5	14.2	2.8	32.0	5.5	29.0	2.5
1917–18	66.0	1.3	10.9	−.5	8.8	−2.6	22.7	−3.8	23.7	−2.8
1918–19	66.5	1.8	8.9	−2.5	8.0	−3.4	23.0	−3.5	22.7	−3.8
1919–20	64.2	−.5	12.2	.8	12.6	1.2	26.2	−.3	27.6	1.1
1920–21	65.0	.3	10.8	−.6	10.7	−.7	28.8	2.3	25.8	−.7
1921–22	63.8	−.9	21.7	10.3	13.6	2.2	32.0	5.5	28.5	2.0
1922–23	65.2	.5	9.0	−2.4	10.3	−1.1	28.3	1.8	25.4	−1.1
1923–24	66.1	1.4	8.7	−2.7	8.6	−2.8	13.6	−12.9	23.5	−3.0
1924–25	62.4	−2.3	7.8	−3.6	17.8	6.4	32.1	5.6	31.9	5.4
Average	64.7		11.4		11.4		26.5		26.5	
1925–26	64.4		----------		12.1	.7	----------		27.2	.6

Station group	Ocean temperature		C Observed		C Computed		D Observed		D Computed	
Year	T	t	R	r	R	r	R	r	R	r
1916–17	63.6	−1.1	28.1	4.7	27.2	3.8	18.3	1.5	20.6	3.8
1917–18	66.0	1.3	21.1	−2.3	19.4	−4.0	14.0	−2.8	13.2	−3.6
1918–19	66.5	1.8	17.0	−6.4	18.1	−5.3	14.9	−1.9	12.0	−4.8
1919–20	64.2	−.5	27.4	4.0	25.1	1.7	18.8	2.0	18.4	1.6
1920–21	65.0	.3	25.9	2.5	22.4	−1.0	12.7	−4.1	16.1	−.7
1921–22	63.8	−.9	36.0	12.6	26.5	3.1	30.2	13.4	19.9	3.1
1922–23	65.2	.5	20.2	−3.2	21.8	−1.6	14.8	−2.0	15.3	−1.5
1923–24	66.1	1.4	15.2	−8.2	19.1	−4.3	12.7	−.9	12.9	−3.9
1924–25	62.4	−2.3	19.7	−3.7	32.0	8.6	13.7	−3.1	25.5	8.7
Average	64.7		23.4		23.4		16.8		16.8	
1925–26	64.4		----------		24.4	1.0	----------		17.8	1.0

Station group	Ocean temperature		E Observed		E Computed		F Observed		F Computed		G Observed		G Computed	
Year	T	t	R	r	R	r	R	r	R	r	R	r	R	r
1916–17	63.6	−1.1	32.1	2.3	34.5	4.7	13.0	1.3	15.0		15.0	3.3		
										3.3	27.6	−.1	29.4	1.7
1917–18	66.0	1.3	24.0	−5.8	25.1	−4.7	9.9	−1.8	8.7	−3.0	23.5	−4.2	26.0	−1.7
1918–19	66.5	1.8	25.8	−4.0	23.5	−6.3	10.3	−1.4	7.8	−3.9	29.6	1.9	25.5	−2.2
1919–20	64.2	−.5	34.9	5.1	31.9	2.1	12.4	.7	13.1	1.4	28.0	.3	28.4	.7
1920–21	65.0	.3	21.7	−8.1	28.6	−1.2	9.5	−2.2	10.9	−.8	31.0	3.3	27.3	−.4
1921–22	63.8	−.9	49.1	19.3	33.6	3.8	22.6	10.9	14.4	2.7	34.7	7.0	29.0	1.3
1922–23	65.2	.5	30.0	.2	27.9	−1.9	10.1	−1.6	10.4	−1.3	27.2	−.5	27.0	−.7
1923–24	66.1	1.4	23.3	−6.5	24.7	−5.1	8.8	−2.9	8.5	−3.2	14.5	−13.2	25.9	−1.8
1924–25	62.4	−2.3	27.4	−2.4	40.5	10.7	8.8	−2.9	19.4	7.7	33.2	5.5	31.4	3.7
Average	64.7		29.8		29.8		11.7		11.7		27.7		27.7	
1925–26	64.4		----------		31.0	1.2	----------		12.5	.8	----------		28.1	0.4

A negative correlation between temperature and rainfall is indicated for each group, but there is only a rough numerical agreement between the computed and observed values. That is, but little significance can be attached to the numerical results of the computation. A comparison of the signs of the observed and computed departures indicates an agreement about 80 per cent of the time. The seasonal rainfall estimated for 1925–26 is entered in the last line. The same results are shown graphically by Figures 2 to 8, in which values of the rainfall are plotted as ordinates against years as abscissæ. The trend of the dashed lines (observed rainfall) agrees with that of the full lines (computed rainfall). The full lines are continued one year beyond the dashed lines in order to indicate the estimated rainfall for 1925–26. In Figure 9 the observed rainfalls for each of the independent groups *a*, *b*, *c*, and *e* are plotted as ordinates against the computed values, as abscissæ. The scattering of the plotted points about the full line gives some idea as to the agreement between computed and observed values, and accordingly the reliability of a forecast. Over 75 per cent of the points lie between the two dashed lines corresponding to errors equal to or less than 2 inches,

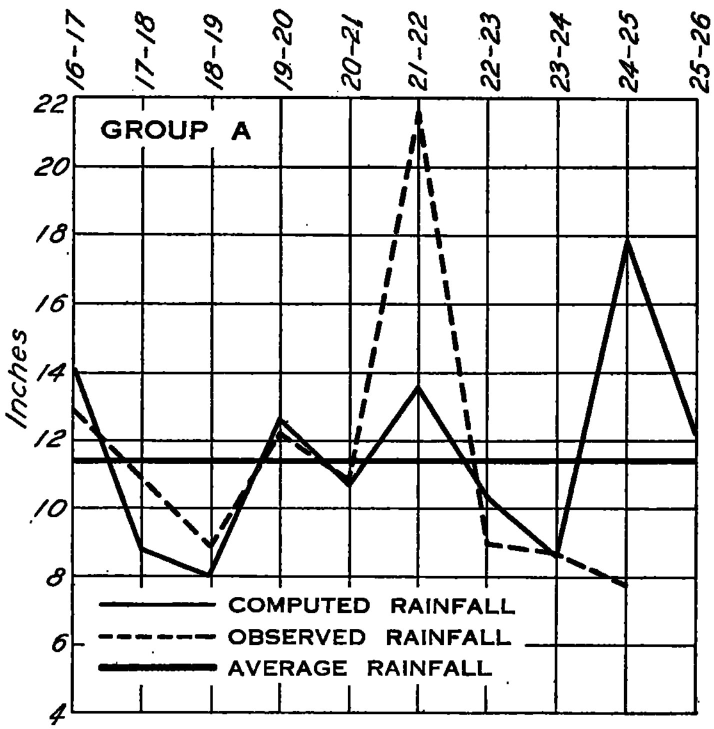

FIG. 2.—Predicted versus observed rainfall at low altitudes not far from the coast

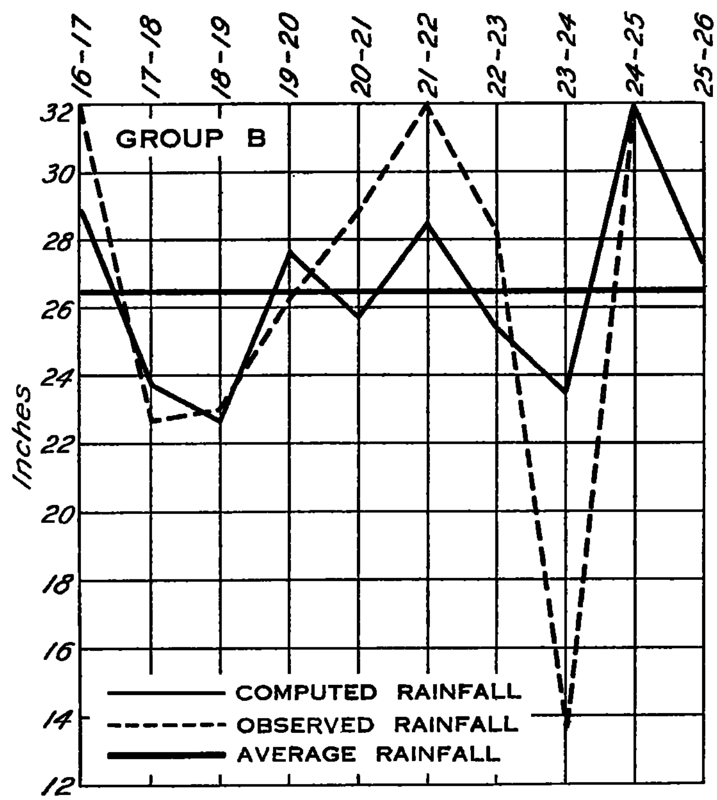

FIG. 3.—Predicted versus observed rainfall at high altitudes farthest from the coast

The question arises, will the relation indicated by the comparatively short series of observations continue to hold? Is the relation merely accidental or does it follow from an actual physical relation between rainfall and a complex of factors of which the temperature of the ocean is a partial index? If a reasonable hypothesis can be developed which accounts for results already observed, it will support the presumption of an actual physical relationship, and consequent continuation of the indicated relation. The following hypothesis is offered as a preliminary attempt, subject to amplification and correction as more information becomes available.

Assume that atmospheric moisture is supplied by evaporation from the ocean into the overlying air. Assume that the rainfall in California results from conditions favorable for the precipitation of moisture in the air transferred from the ocean area over the land. Other things being equal, the greater the amount of air transferred from the ocean to the land the greater will be the amount of moisture available for precipitation on the land. There is abundant observational evidence of the existence over the North Pacific Ocean of an area of high pressure, which implies an excess mass of air. The monthly average intensity and area of this HIGH vary periodically from a maximum during late summer to a minimum during late winter. Also this seasonal variation in the atmosphere over the ocean is accompanied by an inverse variation over adjacent continental areas. Thus there is reason to expect a seasonal interchange of vast air masses between the ocean and continents, the transfer being toward the continent after late summer, resulting in the rainy season. However, this transfer is not a uniform or regular process. There is a continual disturbance of equilibrium, due partly to variations in land and ocean temperatures, which produces an irregular turbulent or pulsating movement, tending to restore equilibrium. Direct evidence of such a process is the succession of atmospheric disturbances called storms.

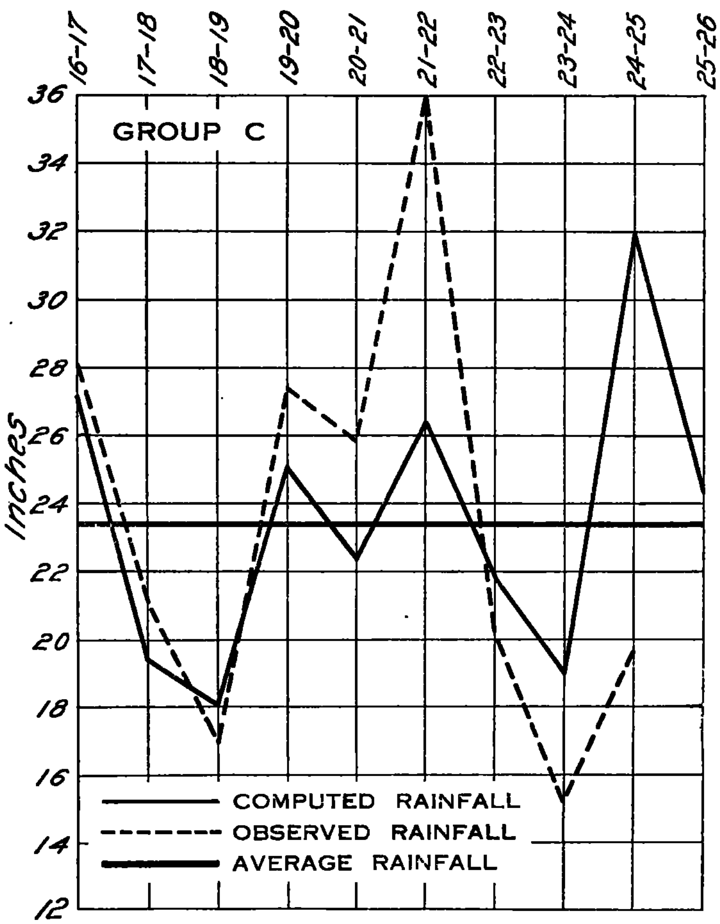

FIG. 4.—Predicted versus observed rainfall at intermediate altitude and distance from the coast

In general, weather conditions vary from year to year. Accordingly, it seems reasonable to suppose that the mass of air over the ocean in late summer that is available for transfer to the land during the following winter, or rainy season, varies from year to year. If, after a summer in which the barometric pressure is relatively high or the high pressure area is relatively large, a correspondingly large amount of air is transferred to the land, more moisture would be available for precipitation. Such a condition would be favorable for a wet year. Similarly, a relatively low barometric pressure or small area of high pressure would be followed by conditions less favorable for a supply of water vapor, sufficient to produce the usual amount of rain. According to this hypothesis any index of the extent of the area of high pressure or of the intensity of the "high" would serve to indicate whether the following seasonal rainfall would be light or heavy.

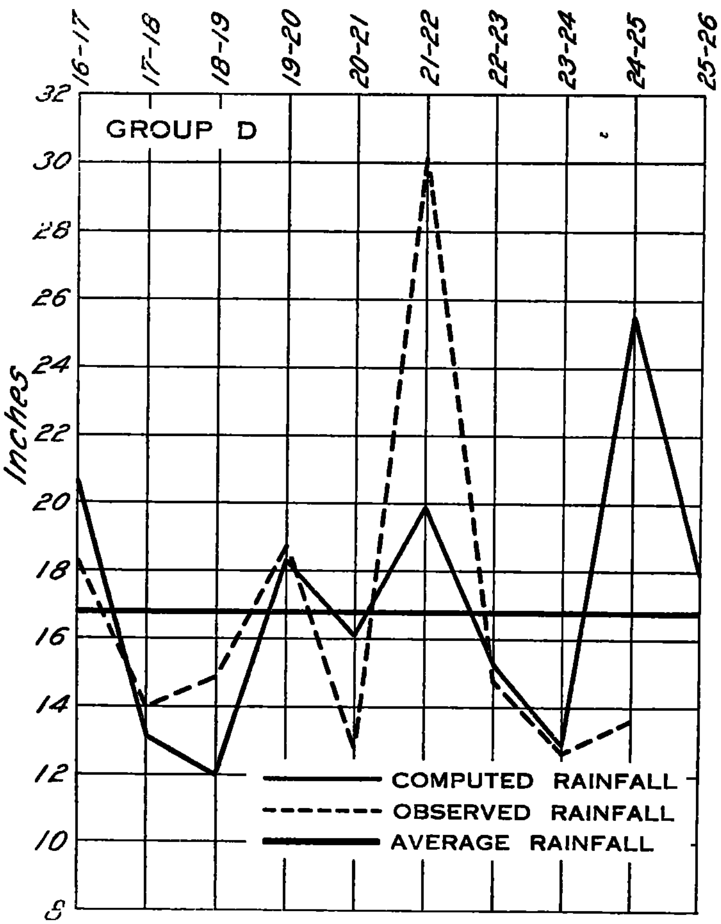

FIG. 5.—Predicted versus observed rainfall, San Diego County, from near coast to 5,000 foot altitude

There is a direct relation between the barometric gradient and wind velocity over the ocean, and there is convincing evidence (McEwen, 1912, 1914, 1916, and 1918) of an inverse relation between ocean temperatures and winds near the Pacific coast of North America. Accordingly, ocean surface temperatures near shore are an index of the condition of the oceanic "high." Moreover, the relation is an inverse one, low temperatures

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correspond to steep barometric gradients, and high temperatures correspond to weak barometric gradients. Therefore the inverse relation found between late summer temperatures of the ocean near shore and the following seasonal rainfall would be expected. Thus ocean temperatures may be used to forecast the relative amount of moisture in the air available for precipitation.

But conditions favorable for precipitating the moisture must also be present in order that rain may result. Thus

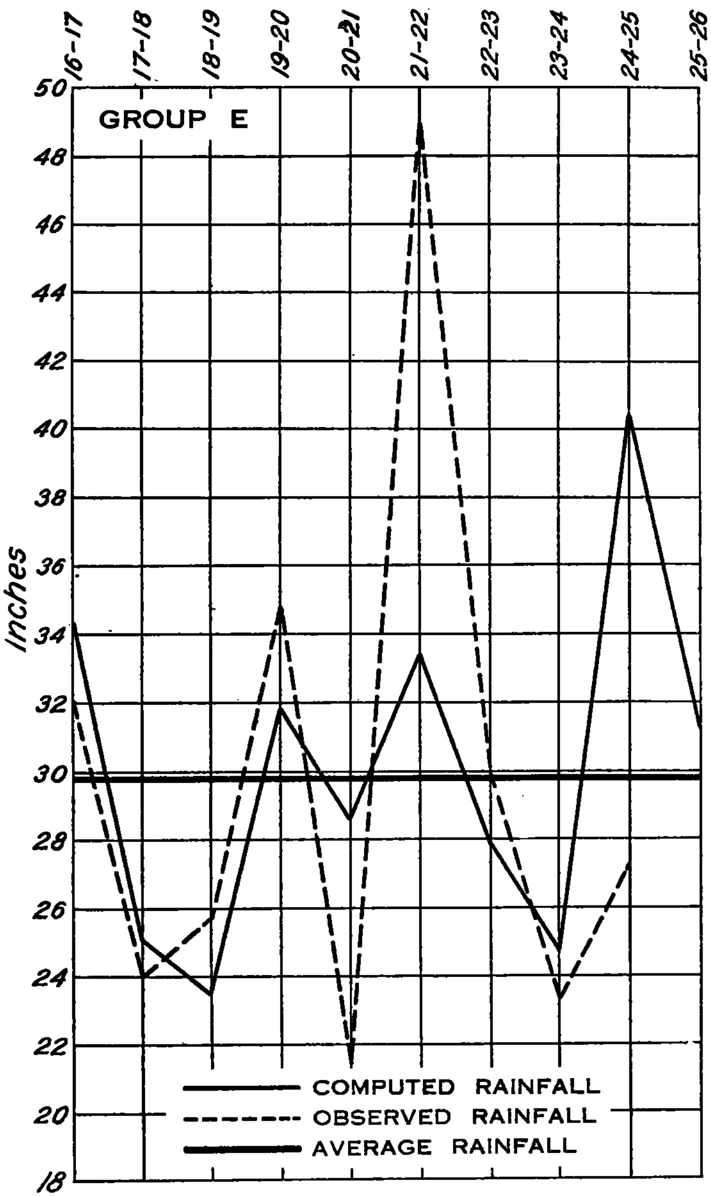

FIG. 6.—Predicted versus observed rainfall at high altitudes in San Diego County, 75 miles from the coast

forecasts of seasonal rainfall are essentially regional, and may fail at times for certain localities, because of an unforeseen lack of conditions necessary for precipitating the available moisture. In fact, an examination of the computed and observed departures of rainfall reveals, as would be expected from the hypothesis, that forecasts of deficient rainfall are more reliable than forecasts of rainfall above the average.

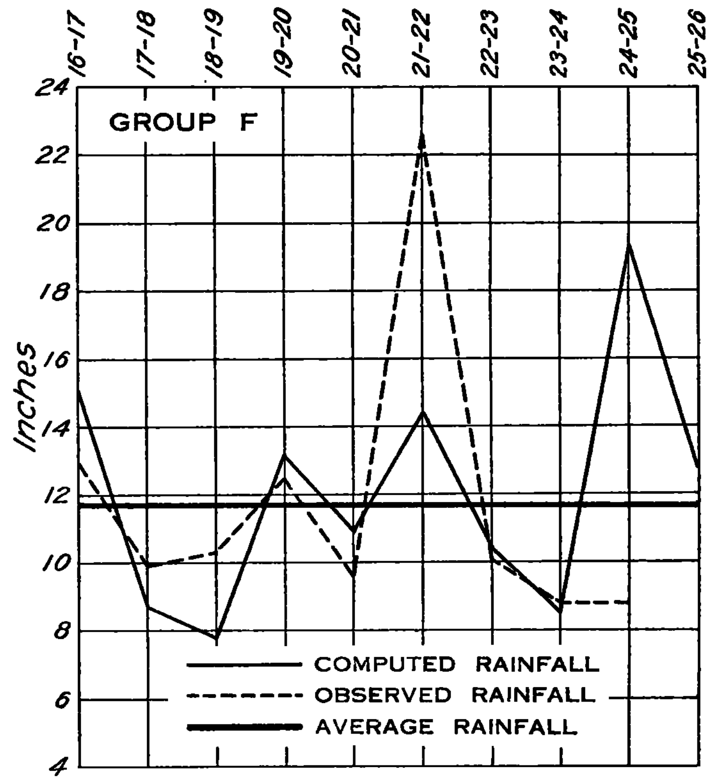

FIG. 7.—Predicted versus oberved rainfall at low altitudes in San Diego County, farthest south

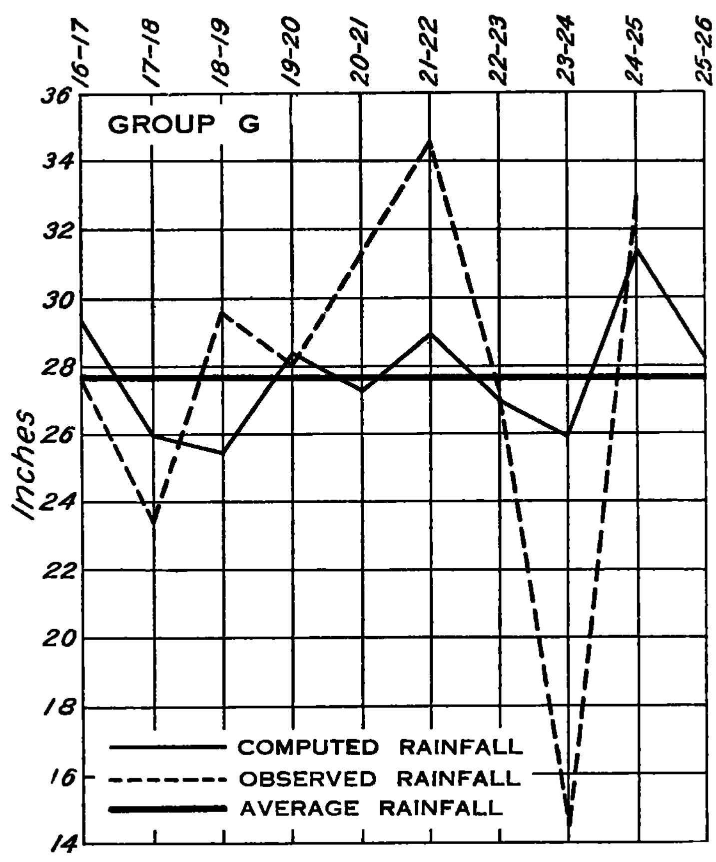

FIG. 8.—Predicted versus observed rainfall at Huntington Lake, highest altitude farthest from coast, and in group farthest north

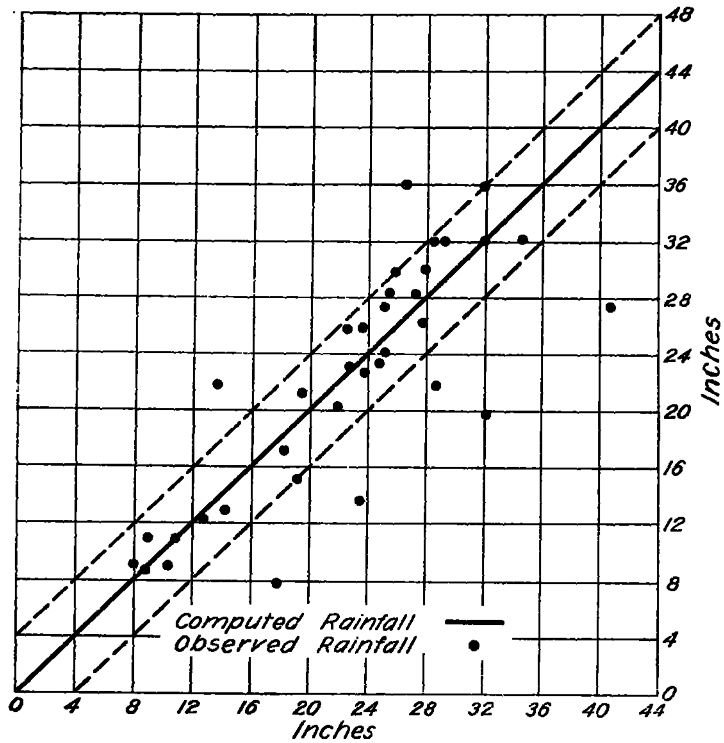

FIG. 9.—Relation of computed to observed rainfall, all groups

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A STUDY OF SEASONAL FORECASTING FOR CALIFORNIA BASED ON AN ANALYSIS OF PAST RAINY SEASONS

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SYNOPSIS

A study in seasonal forecasting is here outlined on the theory that conditions are forming over the Pacific Ocean before the rainy season begins, and also during the opening months, that will, when interpreted, indicate the character of the ensuing rainfall season with a high average of probability.

I have investigated the last 40 seasons (ending 1924–25) for pressure, and for rainfall as far back as records are available. I have ascertained that when low-pressure areas enter directly the central to southern California coast in September or October, there is a ten-to-one probability that the ensuing season (for central and southern California) will be an average to wet one.

I have also collected data to show that in the seasons in which San Diego has above average summer rains (July, August, or September) the ensuing rainy season will likewise be average to wet, with a 90 per cent probability.

The forecast values of appreciable rains in November as far south as Santa Barbara is also considered.

The rainfall for the same seasons in northern, central, and southern California are sometimes proportionately alike while in other seasons they are radically different. Of the seasons in which there are no early movements of LOWS or no summer rains at San Diego, some are still average to wet ones, but all the dry or partly dry seasons follow such rainless summers.

The present status of seasonal forecasting.—The investigation of seasonal forecasting of rainfall for California has until recent years been handicapped by lack of sufficient data. Weather Bureau records for the continental area are abundant, but it is only since 1922 that we have been able to form much idea of conditions over the Pacific through radio reports. Thanks to the success of the San Francisco office of the Weather Bureau in enlisting the cooperation of steamship companies, data from the oceanic area are now being received which will enable us gradually to improve the basis of our attempts at seasonal forecasting for California. This is a subject which, owing to its economic importance, is well worth all the attention any investigator can give to it.

Though seasonal forecasting is a baffling subject, it is not hopeless. The Indian meteorologists have for many years studied the movements and intensities of the monsoons as affecting and forecasting the rainfall of India a few months in advance, and their efforts have met with considerable success. For southern California, McEwen has investigated the relation between the water temperatures off the coast in summer and the rainfall of the following rainy season. His method has so far produced very encouraging results. But we are still in the pioneer stage of long-range forecasting, and conclusions must be accepted tentatively and held open to revision as data accumulates.

Three divisions of the State for rainfall.—This State is so generally considered as northern and southern California that meteorologists have fallen into the same habit. I believe, however, that it is much more accurate to divide it into three sections, northern, central, and southern. Even this demarcation is somewhat vague; however, as nearly as seemed practicable, I have drawn the lines of division as follows: A line from northern Marin County to the city of Marysville would divide the northern from the central section, and a line from the coast at Monterey across to Merced would mark the division between central and southern California. Our main discussion will relate to the central and southern California sections. The dry region everywhere east of the Sierra is climatically always in a separate class.

In referring to rainy seasons they are always understood on the Pacific coast to begin with July 1 and to end with June 30. East of the Rockies the season agrees with the calendar year. As to the kinds of rainy seasons, I divide them into four types and consider that any further division would be impracticable. It becomes